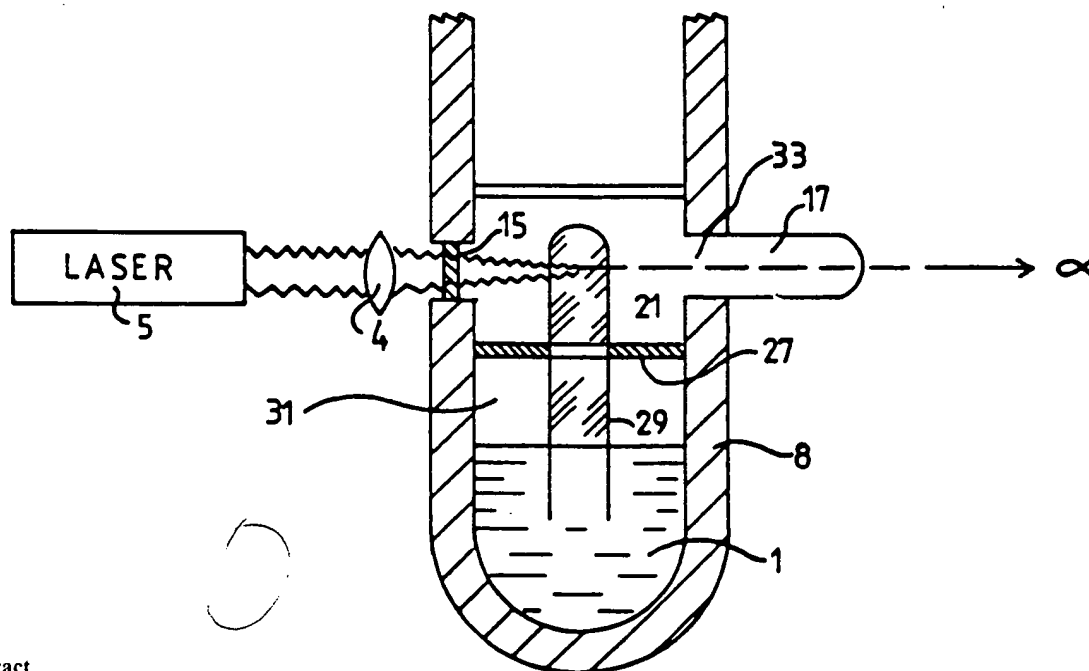37

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(54) Title: METHOD AND APPARATUS FOR FORMING A COHERENT BEAM OF BOSONS HAVING MASS

(57) Abstract

Coherent light from a pulsed laser (5) is focused by a lens (4) onto a liquid helium film (21) formed by capillary action on bent wire (29) in a vacuum chamber (31). A coherent boson beam is produced by the interaction of the laser light with the liquid helium. The boson beam is extracted through a vacuum transport system (17). A fusion reactor using a coherent boson beam so produced is also disclosed.

METHOD AND APPARATUS FOR FORMING
A COHERENT BEAM OF BOSONS HAVING MASS

BACKGROUND OF THE INVENTION

(i)   Field of the Invention

This invention relates to a method and apparatus for forming coherent bosons having mass.

5   (ii)   Prior Art

It is well-known that when intense light from a laser is focused on matter, atoms will absorb energy from photons to become ionized and form a hot plasma. Many works in this field are summarized in
10   the book Plasma and Laser Light, by T. D. Hughes, John Wiley & sons (1976).

It is also that if the light from a laser is powerful enough, say with an intensity greater than 10^{12} watt/cm^2, the atoms will be ionized from the
15   light. Furthermore, the electrons coming out from the atoms will absorb more photons. This is referred to in literature as ATO (= Above Threshod Ionization). See for example P. Kruit et al, Phys. Rev A 15, 1604 (1977): and R. R. Freeman et al. Phys.
20   Rev Let 59 1092 (1987)

The following publications relate to laser cooling for producing an ion beam:
"Possibility of Observing a Condensed Crystalline State in Laser-Cooled Beams of Atomic

Ions, EUROPHYSICS LETTERS, J. P. Schiffer and O. Poulsen, Europhys. Lett., 1 (2), pp. 55-59 (1986).

"Could There be an Ordered Condensed State in Beams of Fully Stripped Heavy Ions?", J. P. Schiffer and P. Kienle, Z. Phys. A. Atoms and nuclei 321, 181 (1985).

According to this invention there is provided a process whereby if the particles in the matter have a density n sufficiently high as to be larger than a critical density n_c and the temperature lower than a critical temperature T_c.

$$n > n_c \qquad\qquad (1)$$
$$T < T_c$$

then when intense light from a laser shines on them, bosons will be released upon absorption of the photons, and become a beam of coherent bosons. These bosons may be neutral atoms, ionized atoms, molecules, or nuclei. The mechanism is induced scattering, as outlined in International patent application No. PCT/AU86/00212.

BRIEF SUMMARY OF THE INVENTION

According to the invention there is provided a method for forming coherent bosons having mass comprising causing coherent light to be incident on dense matter.

BRIEF DESCRIPTION OF THE DRAWING

The invention is further described by way of example only with reference to the accompanying

drawing, the single figure of which is a diagram of an apparatus constructed in accordance with the invention.

DETAILED DESCRIPTION

5   When a system of bosons is under thermal equilibrium, the distribution of their energy obeys Bose-Einstein statistics. If the density of the bosons increases, or the temperature of the bosons decreases, a critical condition is reached and some

10   of the bosons will share the same ground state at the lowest energy and become coherent. This is called Bose-Einstein condensation, and the temperature at which it occurs is the critical temperature. A more thorough discussion concerning Bose-Einstein

15   condensation is given in, for example, the book "Statistical Physics" by L.D. Landau and E.M. Lifshitz, Pergamon Press, 1958, at page 168. Let the critical density be n_c and the critical temperature T_c. We have:

20
$$n_c = \int^{\rho} \frac{d^3 p}{e^{E/kT_c}} \qquad (2)$$

where p, E are respectively the momentum and energy of the bosons, T_c is the critical temperature, and k is the Boltzman constant. Upon evaluation of the integral, they are related by

25
$$n_c = (2mkT_c)^{3/2} \, \zeta(3/2) \qquad (3)$$

where $\zeta(3/2) = 2.612$ is the Riemann function and m is the mass of the charged boson. To evaluate the

numerical values, one can assume a temperature of
$10°K$ and a boson of the order of the mass of the
proton, m 1 GeV, and the critical density n_c is
$10^{24}/cm^3$. This is at least an order of magnitude

5   higher than the density of most normal matter.
Hence, almost all normal matter never reaches this
critical condition at this low temperature. Most
matter also becomes solid at $10°K$, and its density
cannot decrease further. The only way to reach the

10   critical temperature or density condition (3) is by
lowering the temperature even further.

For liquid helium, the critical temperature
is reached at $T_c = 2.174°K$, at normal atmospheric
pressure. The corresponding critical density is of

15   the order of $10^{22}/cm$. Once the critical
temperature is reached, some of the helium atoms
(He^4), which are bosons, in the liquid state will
become coherent and form a superfluid component in
the liquid helium. Focusing an intense light from a

20   laser on the superfluid will cause a coherent boson
beam to be formed.

Consider the physical process behind the
interaction of light with a helium atom. If there is
sufficient intensity of light, the helium atom will

25   absorb many photons to become ionized.

$$n_\gamma \gamma + He \rightarrow \alpha + \bar{e} + \bar{e} \qquad (4)$$

Energy requirement dictates that

$$n_\gamma \gamma E \gg E_{He} \qquad (5)$$

where E is the energy of ach individual photon, and
E_{He} is the ionization energy of the helium
(=27.2eV). If the energy of the photon in the laser
is E = 1eV, it requires at least the absorption of

5   28 photons by an individual helium atom to become
ionized. According to quantum electrodynamics the
probability of absorbing each additional photon is
down by $\propto \sim \frac{1}{137}$ so that the chance of ionization
from ordinary light is extremely small. It requires

10   very intense light from a laser to ionize a helium
gas. Once the helium is ionised, the absorption of
additional photons is generally done by electrons,
and the electrons, and the ionized helium atoms, will
become hot.

15   However, if the helium atoms are coherent as
they are in a superfluid liquid helium state, then
there is collective interaction among the coherent
photons and coherent helium atoms. Then we may have
a coherent neutral helium beam in the final state

20     $$n_\gamma \gamma + n_o He \rightarrow n_\gamma \gamma + n_o He \quad (6)$$

if the energy of photons is not used up for
ionization.

           On the other hand, the helium may become
ionized and separate into a coherent beam of
25   particles and electrons.

$$n_\gamma \gamma + n_o He \rightarrow n_i \alpha + 2n_i (\bar{e} + e) \quad (7)$$

where n_γ is the number of coherent photons, n_o is
the number of coherent helium atoms, and n_i is the

number of coherent α- particles ($n_i = n_o$). As
discussed in patent application PCT/AU86/00212, in
the scattering among coherent particles, there is a
factor m! increase in probability whenever there is m
5   coherent bosons. So the probability that (6) and (7)
occurs instead of (4) has an additional factor like
($n_\gamma! \, n_o! n_i!$). For a 1 Joule light with a pulse
of 10 ns from a single mode Nb-YAG laser or an Eximer
laser, there are $n_\gamma = 10^{19}$ photons. For superfluid
10   liquid helium, there are about 10^{22} helium atoms in
1 cm^3. For a liquid film of the size 10 mm x 10 mm
x 1mm, there are n_o 10^{12} atoms. So, for the
scattering of coherent light with superfluid helium,
the probability of producing coherent bosons is
15   practically 1, and the scattering can be regarded as
a semiclassical scattering.

The critical condition for creation of
coherent bosons is discussed in the aforementioned
patent application PCT/AU86/00212. More
20   particularly, the ratio "r" is therein defined as:

$$r = \frac{W_c}{W_o} \quad \text{where}$$

W_c = rate of coherent scattering, and
W_o = rate of normal scattering

25   For production of coherent bosons, the
critical condition is $r \gtrless 1$. That is to say, coherent
bosons will be produced if the rate of coherent
scattering equals or exceeds the rate of normal
scattering.

30   In the context of the system described in
application PCT/AU86/00212, the ratio "r" is there

expressed as:

$$r = \frac{(n_1 + n_2)!}{n_2!} \eta \qquad \text{where}$$

n_1 = number of photons,

n_2 = number of coherent particles, and

η = phase space factor.

In the present context, it is convenient to consider the critical condition as being described by the equation for process (6)

$$W_c \simeq Z^{n_\gamma} W_1 \quad , \quad \text{where}$$

W_c is as above defined,

W_1 is the rate of normal scattering, and

$$Z = n_\gamma \, m^3 \, \tilde{P_1} \, \eta \, e^{N\epsilon - 1} \qquad \text{where}$$

m = the number of coherent helium atoms,

$\tilde{P_1}$ = possibility of normal photo scattering,

$$\eta = \frac{1}{\text{number of final states}}$$

e is the exponential number

N = the number of photons per helium atom, and

$\epsilon = \dfrac{\omega}{M}$, where

ω = frequency of photons, and

M = mass of helium atom

In this case the critical condition for production of coherent bosons is:

$$Z \gtrless 1 .$$

For $n_\gamma = 10^{19}$, $m = 10^{10} \sim 10^{17}$,

$N = 10^2 \sim 10^7$, $\epsilon = 2-7 \times 10^{-10}$, $N\epsilon$ is very small

and can be neglected. The critical condition becomes

$$\frac{n_\gamma\, m^3}{e^2}\, \tilde{P}_1\, \eta \gg 1$$

Insight into this critical condition may be gained by considering the case where $m=m_\gamma$, the number of helium atoms is equal to the number of photons and each helium interact with only one photon. Then eq. (5.19) reduces to

$$n_\gamma \gg \left(\frac{1}{e^4 \tilde{P}_1 \eta}\right)^{\frac{1}{4}} \tag{5.20}$$

where

$$\tilde{P}_1 = \frac{\sigma_1 T}{4V} \sim 2.0 \times 10^{-27} \frac{T}{A}\ cm^2$$

$$\eta = \frac{\pi T}{\omega^2 A} = 1.90 \times 10^{-18} \frac{T}{V}\ cm^2 \tag{5.21}$$

and the γ-He scattering cross section σ_1 is given by Rayleigh theory to be

$$\sigma_1 = \frac{8\pi}{3}\left(\frac{e^2}{m_e c^2}\right)^2 \left(\frac{\omega}{\omega_0}\right)^4 \tag{5.22}$$

at wave length $\lambda=0.488$ μm, or $\omega=2.54$eV; ($\omega_0=13.6$eV). Condition (5.20) becomes

$$n_\gamma \gg 1.23 \times 10^{10} \left(\frac{V}{T}\right)^{\frac{1}{2}} \tag{5.23}$$

where the volume V is the square root of the product
of normalization volume for helium V_{He} and the
volume of laser pulse V_γ

$$V = \sqrt{V_{He} \, V_\gamma} \qquad\qquad (5.24)$$

5   which are given by the experimental condition.

         The interaction time T cannot be determined
exactly by the above but the smallest value T can
take is the period of the light wave. For
$V \sim 10^2 cm$, $T \sim 1\mu m$, the critical condition is
10       $n_\gamma \gtrsim 10^{13}$. If the laser pulse has energy μJ
or above, the critical condition will be satisfied.

         Generally, while it is not necessary for
existence of the critical condition $z \gtrsim 1$ that the
aforementioned critical temperature T_c or critical
15   density n_c prevail it is preferable that such be
the case. Particulaly, as above described, for
superfluid helium the described Nb-YAG or Eximer
lasers provide sufficient energy ($n_\gamma = 10^{19}$
photons) to ensure effective coherent boson
20   production, the superfluid helium being at the
critical temperature. In the case where the bosons
upon which the coherent light is incident are at a
temperature exceeding the critical temperature, the
critical condition for coherent boson production may
25   still be met, however, by increasing the number of
the incident coherent photons.

The requirements in this respect are, considering the case of production of coherent helium atoms only, ascertainable from the following equation:

$$W_c = \frac{(n_\gamma !)^3 \, (m!)^\nu}{(N!)^{2m}} \, (\tilde{P}, \, n)^{n_\gamma - 1} \, e^{N n_\gamma \varepsilon} \, W_1 \, ,$$

5   where the terms thereof have the meanings described above.

10   Because of momentum conservation, the produced coherent boson beam will tend to travel along the direction of an incident photon beam. If the average number of photons absorbed by helium is large, the final state will contain coherent He particles. For the above example $n = 10^{19}$, n_0 10^{12}, and $E_\gamma = 1eV$, the energy of individual He

15   particles in the final coherent beam is given by $(n_\gamma E/n_0) \, E_\gamma \sim 10^7 eV$.

So, a beam of coherent He particles with energy above MeV is formed. For a 10MeV He particle, the speed is 2×10^{10} cm/sec. The time interval for it to pass through the thickness of the

20   plasma of 1μm is 5×10^{-15} sec. The power contained in the coherent α-beam is:

$$P = \frac{1J}{5 \times 10^{-15}} = 2 \times 10^{14} \, watt \tag{8}$$

This is a very substantial concentration of power. Such a powerful beam has many applications including

25   to initiate nuclear fusion in a deuterium pellet under inertia confinement configuration.

The energy of individual coherent bosons
produced in the final beam can be adjusted by
changing the number of helium atoms of the superfluid
component of the liquid helium. The higher the

5   temperature, the lower the component of superfluid,
and the higher the energy of the resultant coherent
energy beam.

EXAMPLE APPARATUS

The apparatus is illustrated in the drawing
10   as consisting of three major components:

(1)   A pulsed laser 5 and its accessories. It
may for example be a pulsed Excimer laser like the
HE-400-5M or TE-290 series manufactured by Lumonic,
3629 Vista Mercado, Camarillo, CA 93010 USA. Or, it
15   may be a pulsed Nd-YAG laser such as the DCR-3G(1)
manufactured by Spectra-Physics, 1250 West
Middlefield Road, P.O. Box 7013, Mountain View, CA
94039-7013, USA.

The laser light is focused into a very small
20   spot on a liquid helium film by a lens 4.

(2)   Cryostat - A cryostat that can hold liquid
helium down to temperature of 1°K or below. Such a
cryostat is described in the book by R. J. Donnelly
entitled Experimental Superfluidity published by The
25   University of Chicago Press (1967), and can be
ordered from Cryo Industries of America, Inc., 24
Keewaydi Drive, Salem NH 03079, USA. Only the
internal part of 8 of the cryostat is shown in the
drawing, this forming a vacuum chamber 31.

(3)   A vacuum chamber 31 inside the cryostat. At
the left-handed side in the figure, a window 15 is
provided open to allow focussed light from the laser
to enter the cryostat. At the right-hand side in the
figure, a vacuum transport system 17 is provided
leading out of the cryostat, where the coherent boson
beam is extracted. In the middle of the chamber is
an inverted U-shaped bent wire 29 within which a
liquid helium film 21 is formed by, for example,
capillary action from a resevoir 23 of liquid helium
in the vacuum chamber 31.

The laser emits pulsed light which enters
the cryostat through the window slit and shines on
the liquid helium film at $1^\circ K \sim 2^\circ K$. The helium
liquid, in this case superfluid helium liquid, will
wet the bent wire from a pool of liquid helium in a
reservoir 23 below the wire and within the cryostat
8. To avoid heating the liquid helium directly from
laser light, it is advisable to provide insulation 27
between the vacuum chamber that holds the liquid
helium film and the liquid helium reservoir below.
Further, some means for locally heating the periphery
of the interior wall of the vaccuum chamber may be
provided at the location between the surface of the
liquid helium and the insulation 27, sufficient to
slightly heat the wall at that location above the
temperature for formation of superfluid helium liquid
at that location. On the other side of the vacuum
chamber a port 33 leads to the transport system 17.
The laser light falls on the liquid helium film and
this gives rise to a coherent He particle beam which
exits via port 33.

Besides using liquid helium as a target it
is also possible to use other materials at
temperature below 2°K. The critical temperature will
differ from material to material, calculable from the

5   density of material by equation (4). Such material
as deuterium will in general be solid at such low
temperature. The deuterium is then in a quantum
solid state. Because it is solid and not liquid, it
does not become superfluid. But, under scattering

10   from coherent light, the coherent deuterium in a
quantum solid state will behave similarly as in the
case of superfluid helium and become ionized and form
a coherent deuterium beam. It is also possible then
to generate other boson beams in similar fashion.

15   The invention may be used for producing
energy by nuclear fusion processes involving
directing one or more coherent beams of coherent
bosons having mass to material capable of undergoing
nuclear fusion such as deuterium and/or tritium. In

20   this application the beam formed by the invention
may, if necessary, be accelerated by use of
conventional accelerators before being so directed.
The material against which the beam is directed may,
for example, be in the form of pellets, as known, and

25   several beams may be directed simultaneously from
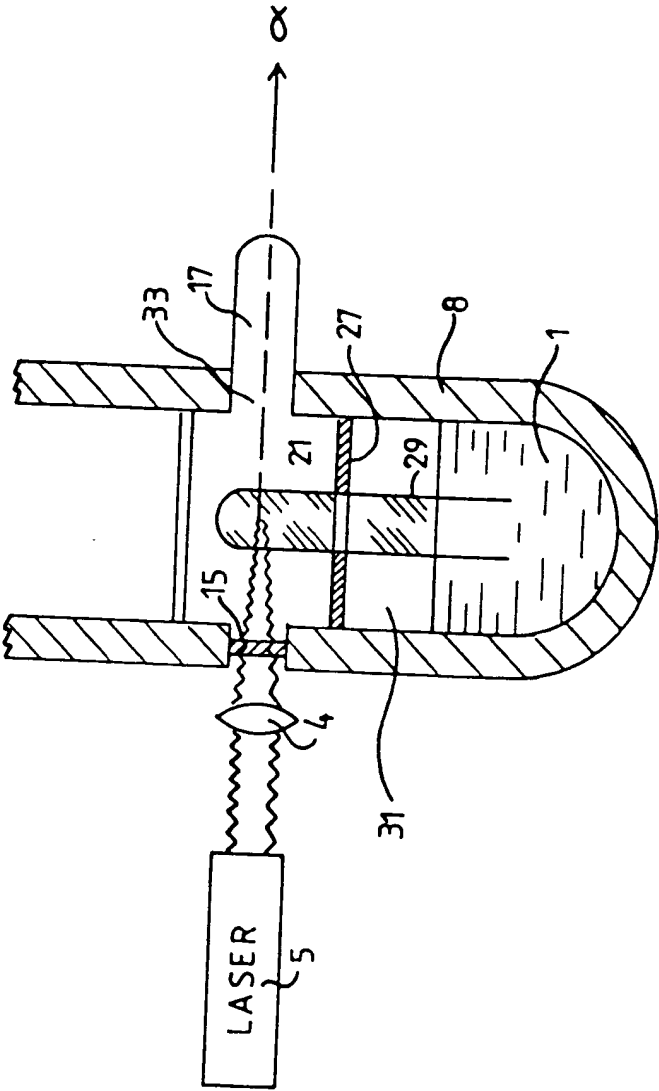different directions.

CLAIMS:

1.   The method for producing coherent bosons having mass comprising causing coherent light to be incident on dense matter.

2.   The method claimed in claim 1 wherein the dense matter is at low temperature.

3.   The method claimed in claim 1 or claim 2 wherein the matter has density greater than a critical density.

4.   The method claimed in any one of claims 1 to 3 wherein the matter is liquid helium.

5.   The method claimed in claim 4 wherein the liquid helium has superfluid properties whereby the coherent bosons are helium or alpha-particles.

6.   The method claimed in any one of claims 1 to 3 wherein the matter is solid deuterium at low temperature.

7.   The method claimed in claim 4 wherein said critical density is of the order of $10^{22}/cm^3$.

8.   Apparatus for producing coherent bosons having mass comprising means for retaining dense matter, a laser for producing coherent light and means for directing the laser light to the matter to produce the coherent boson.

9.   Apparatus as claimed in claim 8 including means for retaining liquid helium for incidence of said coherent light beam thereon.

10.   Apparatus as claimed in claim 9 including means for cooling the helium to very low temperatures.

11.   A fusion reactor comprising means for retaining dense matter, a laser for producing coherent light and means for directing the laser light to the matter to produce the coherent bosons having mass and means for directing the coherent boson beam to material capable of undergoing nuclear fusion.

12.   A method of generating energy by nuclear fusion comprising forming coherent bosons having mass by causing coherent light to be incident on dense matter and directing the coherent bosons to material capable of undergoing nuclear fusion.

FIG1

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.^{4} HO5H 3/02, 1/24, G21B 1/02

II. FIELDS SEARCHED

Minimum Documentation Searched ?	
Classification System	Classification Symbols
IPC	HO5H 1/00, 1/24, 3/00, 3/02, H01S 4/00, G21B 1/02

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched *

AU :   IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT *

Category *	Citation of Document, ** with indication, where appropriate, of the relevant passages **	Relevant to Claim No. **
X	US,A, 3723703 (EHLERS et al) 27 March 1973 (27.03.73)	(1-3,6,8)
A	DE,A1, 3409478 (LANGE) 31 January 1985 (31.01.85)	
A	WO,A1, 87/00681 (APRICOT SA) 29 January 1987 (29.01.87)	

* Special categories of cited documents: **

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the International filing date but later than the priority date claimed

"T" later document published after the International filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
12 January 1989 (12.01.89)	25 JANUARY 1989 (25.01 89)
International Searching Authority Australian Patent Office	Signature of Authorized Officer F. SPANN

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Members					
US 3723703	DE	2205236	FR	2124573	GB	1333542
WO 87/00681	AU	61947/86	BR	8606780	CN	86105630
	DD	251664	DK	1527/87	EP	232330
	ES	2000736	FI	871300	GB	2191336
	HU	44871	IL	79437	MC	1810
	NO	871238	PL	260805	PT	83069
	ZA	8605567				

END OF ANNEX

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